

**Analysis and Design
of Analog
Integrated Circuits**
Third Edition

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To Liz and Judy

worst case W/L mismatch is 2 percent, the device thresholds are identical, $X_1 = 0$, and the load resistors are identical.

3.21 For the circuit of Fig. 3.57a, determine the input offset voltage if the transistor base widths mismatch by 10 percent but otherwise the circuit is balanced.

3.22 For the circuit of Fig. 3.68, determine the input offset voltage if the JFET channel widths mismatch by 10 percent but otherwise the circuit is balanced. Assume that $I_{DSS} = 1 \text{ mA}$, $V_p = -2 \text{ V}$. The bias current is much lower than I_{DSS} and so the dominant offset contribution is ΔV_p .

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Chapter 4

Transistor Current Sources and Active Loads

4.1 Introduction

Current sources made by using active devices have come to be widely used in analog integrated circuits both as biasing elements and as load devices for amplifier stages. The use of current sources in biasing can result in superior insensitivity of circuit performance to power-supply variations and to temperature. Current sources are frequently more economical than resistors in terms of the die area required to provide bias current of a certain value, particularly when the value of bias current required is small. When used as a load element in transistor amplifiers, the high incremental resistance of the current source results in high voltage gain at low power-supply voltages.

The first section of this chapter analyzes the basic types of current-source circuits that are commonly used in both bipolar and MOS technology. In the first section of this chapter, the output current and output resistance of each type are considered and the effects of device mismatches are analyzed. The second section of the chapter deals with the design of bias circuits for integrated circuits, with the objective of obtaining insensitivity of bias currents to temperature and power-supply voltage variations. Finally, the use of the transistor current source as a load element in amplifier stages is considered.

4.2 Current Sources

4.2.1 Simple Current Source

The simplest form of current source consists of a resistor and two transistors, as shown in Fig. 4.1 using bipolar transistors. Transistor Q_1 is diode connected, forcing the collector-base voltage to zero. In this mode, no injection takes place, and the collector-base junction since it is at zero bias, and the transistor behaves as if it were in the forward-active region. We will neglect junction leakage currents, assume identical transistors, and assume that the output resistance of Q_1 is infinite. Since Q_1 and Q_2 have the same base-emitter voltage, their collector currents are equal:

$$I_{C1} = I_{C2} \quad (4.1)$$

Summing currents at the collector of Q_1 yields

$$I_{ref} - I_{C1} - 2 \frac{I_{C1}}{\beta_F} = 0$$

and thus

$$I_{C1} = \frac{I_{ref}}{1 + \frac{2}{\beta_F}} = I_{C2}$$

If β_F is large, the collector current of Q_2 is nearly equal to the reference current:

$$I_{C2} \approx I_{ref} = \frac{V_{CC} - V_{BE(on)}}{R}$$

Thus for identical devices Q_1 and Q_2 , the output and reference currents are equal. Actually, the devices need not be identical; the emitter areas of Q_1 and

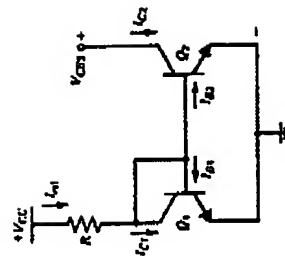


Figure 4.1 A simple two-transistor current source

can be made different, which will cause the I_E values for the two transistors to be different. The two collector currents I_{C1} and I_{C2} will then have a constant ratio rather than being equal, as shown by (4.1). This ratio can be either less than or greater than unity, and thus any desired output current I_{C2} can be derived from a fixed reference current. However, area ratios greater than about five to one consume a large die area because of the area of the larger of the two devices. Thus for the generation of large current ratios, other methods discussed in later sections, are usually preferable. Since the input current is reflected in the output, this circuit is often called a "current mirror."

One of the most important aspects of current-source performance is the variation of the current-source current with changes in voltage at the output terminal. This is characterized by the small-signal output resistance of the current source. For example, the common-mode rejection ratio of the differential amplifier depends directly on this resistance, as does the gain of the active-load circuit. We assumed, in writing (4.1), that the collector currents of the transistors are independent of their collector-emitter voltages. Actually, the collector current increases slowly with increasing collector-emitter voltage, as illustrated in Fig. 4.2. As discussed in Chapter 1, this base-width modulation effect can be represented for large-signal conditions by the expression

$$I_C = I_S \left(\exp \frac{V_{BE}}{V_T} \right) \left(1 + \frac{V_{CE}}{V_A} \right)$$

where V_A is the Early voltage. A typical value of the Early voltage for *npn* transistors is 130 V. Thus, for example, if the collector-emitter voltage of Q_1 is held at $V_{CE(on)}$ and if the collector voltage of Q_2 is at 30 V, then the ratio of I_{C2} to I_{C1} would be

$$\frac{I_{C2}}{I_{C1}} = \frac{1 + \frac{V_{CE2}}{V_A}}{1 + \frac{V_{CE1}}{V_A}} = \frac{1 + \frac{30}{130}}{1 + \frac{0.6}{130}} \approx 1.25 \quad (4.4)$$

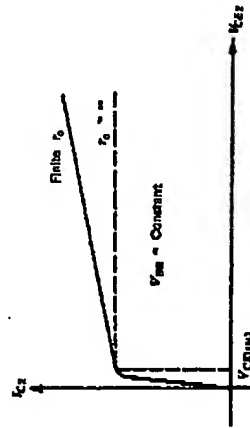


Figure 4.2 Collector characteristics for an *npn* transistor for the hypothetical case of $r_o = \infty$, and the actual case for which r_o is finite.